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Technical and Economical Analysis of a Solar Power System Supplying a Residential Consumer

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Abstract

This paper presents the design and technical-economic analysis of a solar power system for a residential consumer. One of the main objectives is to design an optimal power system based on solar energy resources for a chosen power consumer. The power consumer represents the starting point of the analysis, contains both AC and DC users and, before the design process, the type and variety of the electrical loads has to be well known. This aspect is important in designing the power system topology, to be more economical and compatible with all the power consumers. The aim of the paper is to present the design and functionality of the solar power system, determining the energy production and consumption for the proposed system. Also an important aspect of the paper is the analysis of the system from technical and economical point of view, to present the overall results. The approach is to study the power system, starting from the solar radiation data, which is a known parameter, to calculate the system equipment sizes and power losses and to find an optimal energy production/consumption ratio. To fulfill this task the proposed research methodology is to configure the optimal system structure (solar panels, chargers, inverters), to gather information about the value of the equipment and to deduct the payback period of the system, under normal functioning conditions.

Keywords: renewable energy; solar power system; project financial analisys; power system design; residential consumer.

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1. Introduction

The solar power system basic component is the solar cell, which generates power by absorbing the energy of photons emitted by the Sun. When these photons reach the surface of the solar panel, electrons are transferred through the cell, creating electrical potential energy. The efficiency of these cells is determined by the type of the semiconductor. Thru the years, the efficiency and the production cost of this panels has evolved noticeable. The cell efficiency has grown compared to the previous years and the production costs are much lower due to an increased demand of this technology [1]. The purpose of the paper is to present the design, analysis and simulation of the solar power system, to determine the energy production and to meet the optimal demand of energy consumption for the proposed system. The proposed solar power system is sized for a typical and average residential consumer. After knowing the total power P_t and time usage of the electrical consumers the energy demand can be estimated (E_d). This can give a basic forecast of the energy needs, which the standalone solar power system will provide [1].

Further in the paper, the technical and economic analysis is presented, where the simulation results are discussed and analyzed from a financial perspective. The software used for simulation is HOMER, version 2.68 [12]. For the system investment and payback period study, a Visual Basic-Excel type of program was made by using specific formulas and algorithms to calculate and plot graphs about the financial analysis.

2. Solar power system design for residential consumer

2.1. The design flowchart of the solar photovoltaic (PV) system

Design of the solar photovoltaic (PV) system is presented in the Fig. 1. as an flowchart [5]. The PV array design is influenced by the load demand, by the solar radiation (sun hours) and by the PV panel efficiency, with other cable and thermal losses, considering as accounting losses. The charge controller is chosen based on the output voltage and current rating of the PV system [2]. Also the output of the charge controller is a function of battery parameters. Batteries for photovoltaic, wind or hybrid renewable energy systems are specially built, with no maintenance and a large number of charge-discharge cycles. The lifetime of a battery pack depends on depth of discharge and on temperature. A backup generator should also be considered in the system design, as a backup solution for charging the batteries in days with insufficient solar radiation. The inverter represents the final component of the electrical consumers power supply and converts the unregulated DC power generated by solar PV panels into AC. Such inverters made with special electronic devices are called network inverters and their power rating in function depends on the maximum load demand.

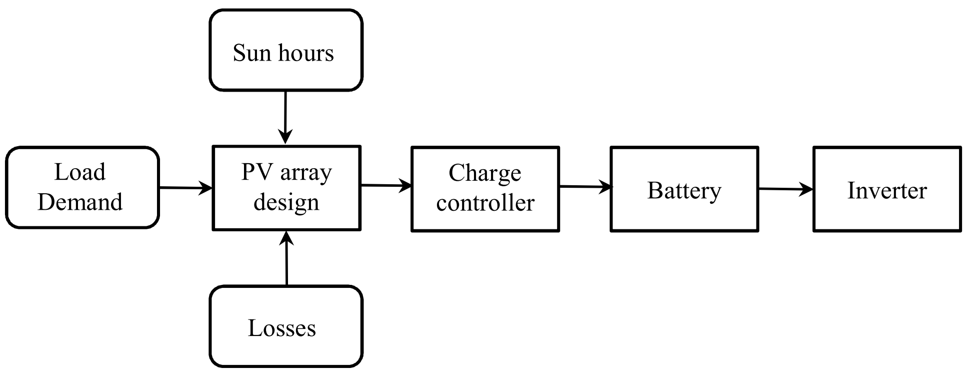

Fig. 1. Isolated solar power system design flowchart

2.2. Electricity demands of the residential consumer

An average household electrical energy demand is presented in Table.1 and detailed in Fig. 2, as a daily profile. The solar PV power system is the designed, planed and implemented for the above mentioned energy demand [3]. The solar PV power system has to supply the proposed consumer [7]. The P_{inst} represents the sum of all installed electrical loads in the residential consumer, and E_d is the approximate energy consumed per day.

Table. 1.

Consumer	Power	Fun. hours	Fun. days
Fridge	200	12	7
TV	70	4	7
Washing machine	1900	1	3
Light bulbs	11*10	3	7
TV receiver	30	4	7
Other	200	4	7

The installed power and daily energy consumption are calculated as follow:

$$P_{inst}= 200+70+3000+11x10+30+200= 3.6kW$$

$$E_d=12*200+4*70+1900+11*10*3+4*30+4*200=5.9\ KWh$$

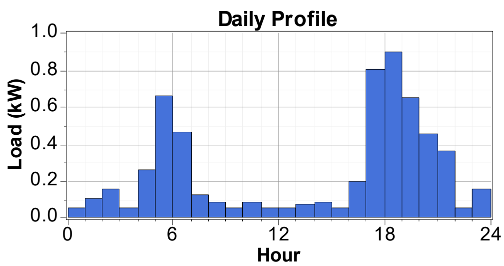

Fig. 2. Residential consumer daily load profile

2.3. Solar PV system design

The solar power systems design [4, 6] starts from the load profile of the consumer. To cover these energy consumption 20 pieces of 245W polycrystalline solar panels are chosen. The solar panel characteristics are: output voltage V_{out}=30.7V; output current I_{out}=7.98A. The PV generated power is slightly larger than necessary because they have to cover all types of losses: cable losses, inverter losses and especially the solar batteries losses.

The proposed configuration for the solar PV panels is with four rows of five panels in a string, which provide an output voltage V_{out}=153.5V and an output current I_{out}=31.9A. The resulting power is P_{out} = (5*30.7) * (4*7.98) = 4.9kW.

The proposed location for this system is the central region of Transylvania. The solar radiation was obtained from an international database and introduced in the studied software (Fig. 3) to model the system behavior.

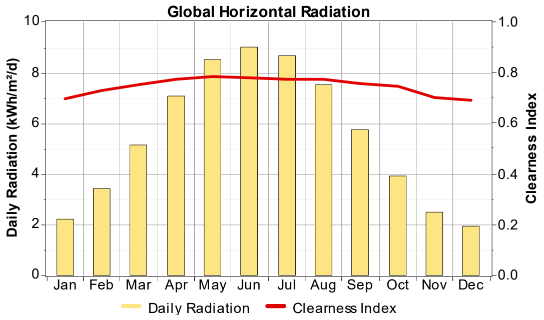

Fig. 3. Solar radiation data for the center Transylvanian area

The battery charger has implemented the function of a maximum power point tracker (MPPT) which permanently monitors the maximum power point with the help of a special algorithm. The wide range of input voltages makes its usage possible with any type of solar PV panels. The integrated maximum power point (MPP) charger, insures a greater amount of energy, 15-30% than when using conventional chargers shunt type and has an input voltage V_{in_max}=600V_{DC}, and charging current I_{out_max}=80A.

For an optimal configuration and maintenance a number of 4 (6V and 530Ah) gel batteries are chosen. The batteries are connected in series, providing an output voltage V_{out_bat}=24V and the capacity of energy stored in the batteries is E_{max_bat}=12.7kWh. The optimal inverter size for this solar PV system is 5000VA and 24V_{DC} input voltage. The output is a pure sine wave, which has a good response at high power startup, reducing losses [8].

3. Technical and economical analysis of the system

3.1. System analysis in HOMER Energy software

The purpose of this analysis is to study the previously presented system in different scenario and configuration. The designed system is modeled in the HOMER Energy [12] software. The proposed solar power system equipment and parameters are inputted in the schematic section Fig. 4.

In the main checkbox the system components are added and the system type can be configured. After the desired system components are checked, the data input is needed for various components. For this model, the data is collected as indicated in the solar PV system design chapter. An optional component is added, and the simulation takes as a different scenario, showing in the results window. Before simulation, constraints are inputted to meet the feasible and optimal results.

3.2. Homer simulation results

After running the simulation, the program provides two optimized results (Fig. 4). One is the proposed system, presented in the design chapter of this paper and the other is with a diesel backup generator added. A constrain option is added to the simulation, as to maximize the capacity shortage of the simulation.

The first optimal result is without considering a backup generator, but with a capacity shortage in the solution. These results represent the worst case scenario, with lack of solar radiation on certain days or with insufficient solar radiation to cover the whole energy demand of a specific day. The second result has a higher initial capital and operation costs, but with the same constrain the capacity shortage is balanced. As the costs are higher the ratability fraction is lower compared to the first result.

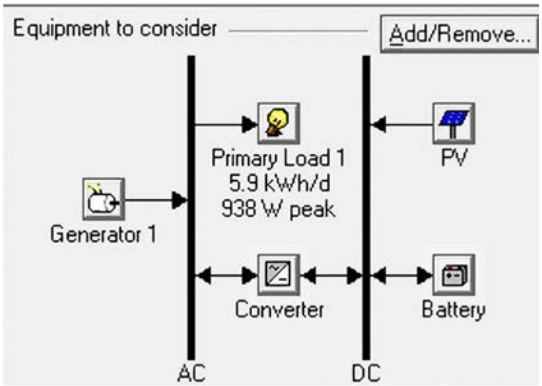

Fig. 4. Equipment and system configuration in HOMER (screen dump)

Optimization Results											
System config.											
PV	Diesel Generator	Battery	Inverter	PV (kW)	Generator (kW)	Battery	Conv. (kW)	Initial Capital	Operating Cost (€/an)	Total NPV	COE (€/kWh)
x	-	x	x	4.9		1	5	7500	123	9074	0.463
x	x	x	x	4.9	1	1	5	9000	250	12191	0.44

Fig. 5. Optimization results in HOMER for the proposed solar power system.

Based on the solar data, the software simulates the PV system energy output. The simulations are performed for a year and with results for each month. Fig. 6 presents the monthly average electrical energy simulation results. The software also provides a simulation of the battery bank state of charge parameter, where simulation shows the charge status of batteries in function of hours per day and charged capacity. Toward the winter season period, the hours and charge state is significantly lower, but enough to provide the demanded energy.

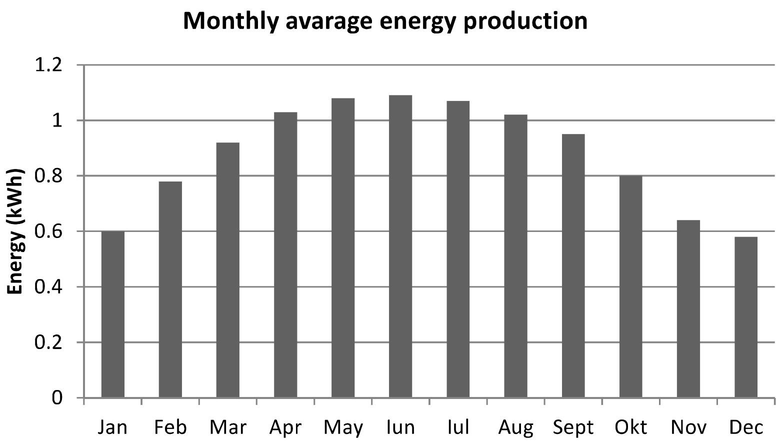

Fig. 6. The studied solar power system average energy production

4. Financial analysis

For the system investment and payback period study, a Visual Basic-Excel type of program [9] [10] was conceived by using specific formulas and algorithms to calculate and plot graphs about the financial analysis (Fig. 7).

The preanalysis is performed for 16 years, but in reality, a similar system can operate 20-25 years at optimal parameters.

The NPV (Net Present Value) is calculated using the formula [11]:

$$NPV = \sum_{t=0}^{T} \frac{(V_t - C_t) - I_t}{(1+ra)^t}$$

where: V_t – income for year t;
C_t – costs for year t;
I_t – investment costs;
ra – actualization ratio;
T – analyzed period.

The initial investment is *9700* Euros and the income for a year is represented by the energy quantity generated by the solar PV power system at the actual market value.

The *NPV* for this analysis at the end of the 16th year is closed by *465.5* euros, and the payback period is over. The condition of acceptance of the investment is that the *NPV>0* at the end of analyzed period. In this case, the investment returns in 16 years of operation, and also this value is the minimum years of investment period. The software was created to stop the graph plot on the first year with the positive NPV, but if we extend to 20-25 years the NPV value is growing. This analysis contains only self-financed project oriented values, and government financing support is not included (Green Certificates to renewable energy producers), which in some cases can reduce the payback period significantly.

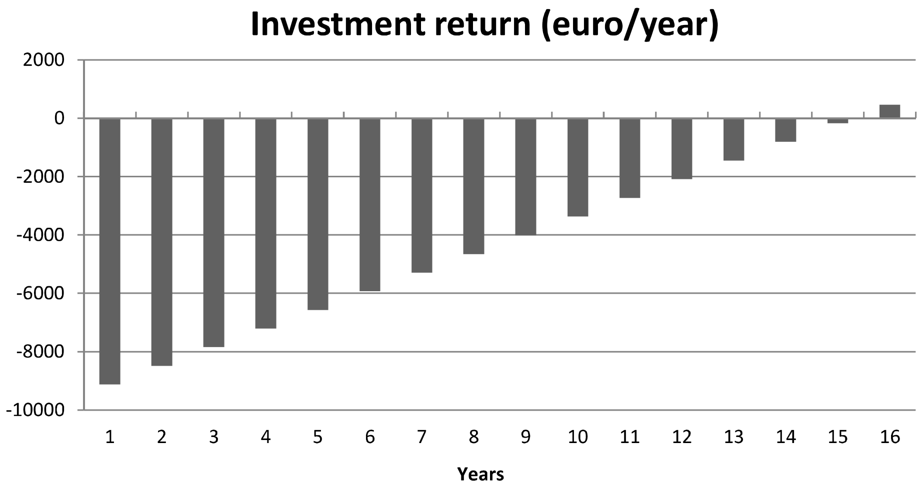

Fig. 7. Visualizing the studied system's investment return period

5. Conclusions

The technical-economic analysis is an important phase in the project implementation, regarding the type of the project or the size of the investment. In this paper the analysis helped to overview the technical and economic factors of the proposed system. If the technical factor and the engineering has no boundaries in designing a solar PV power system, then the economic factors can establish constrains in the design, as seen in the financial overview chapter. For technical analysis is recommended to use dedicated software to check the correct sizing and the balance between system components. After the final design is chosen, a research must be done to obtain the market value of the components. If the working principles of the system and the operation costs are known a financial analysis is necessary to overview the period of investment return as presented in this paper.

6. Acknowledgment

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